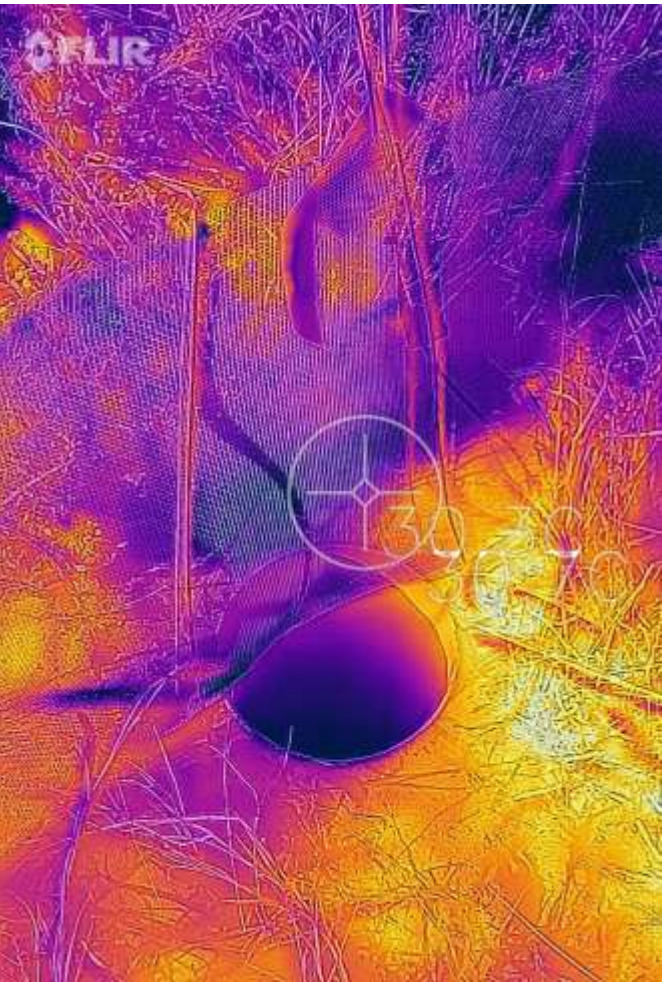
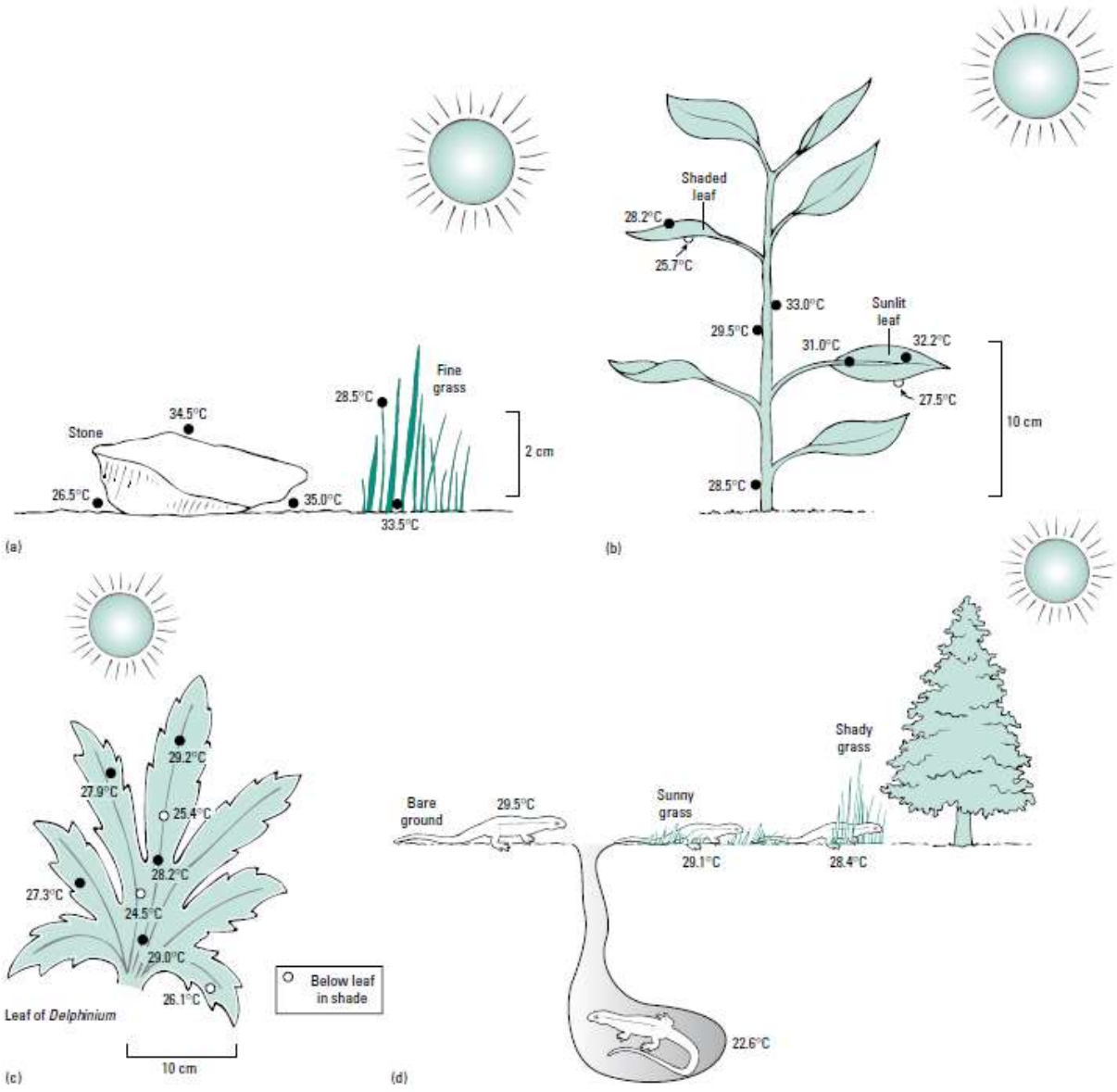
2. Thermal environments and thermal balance

Heat balance considerations

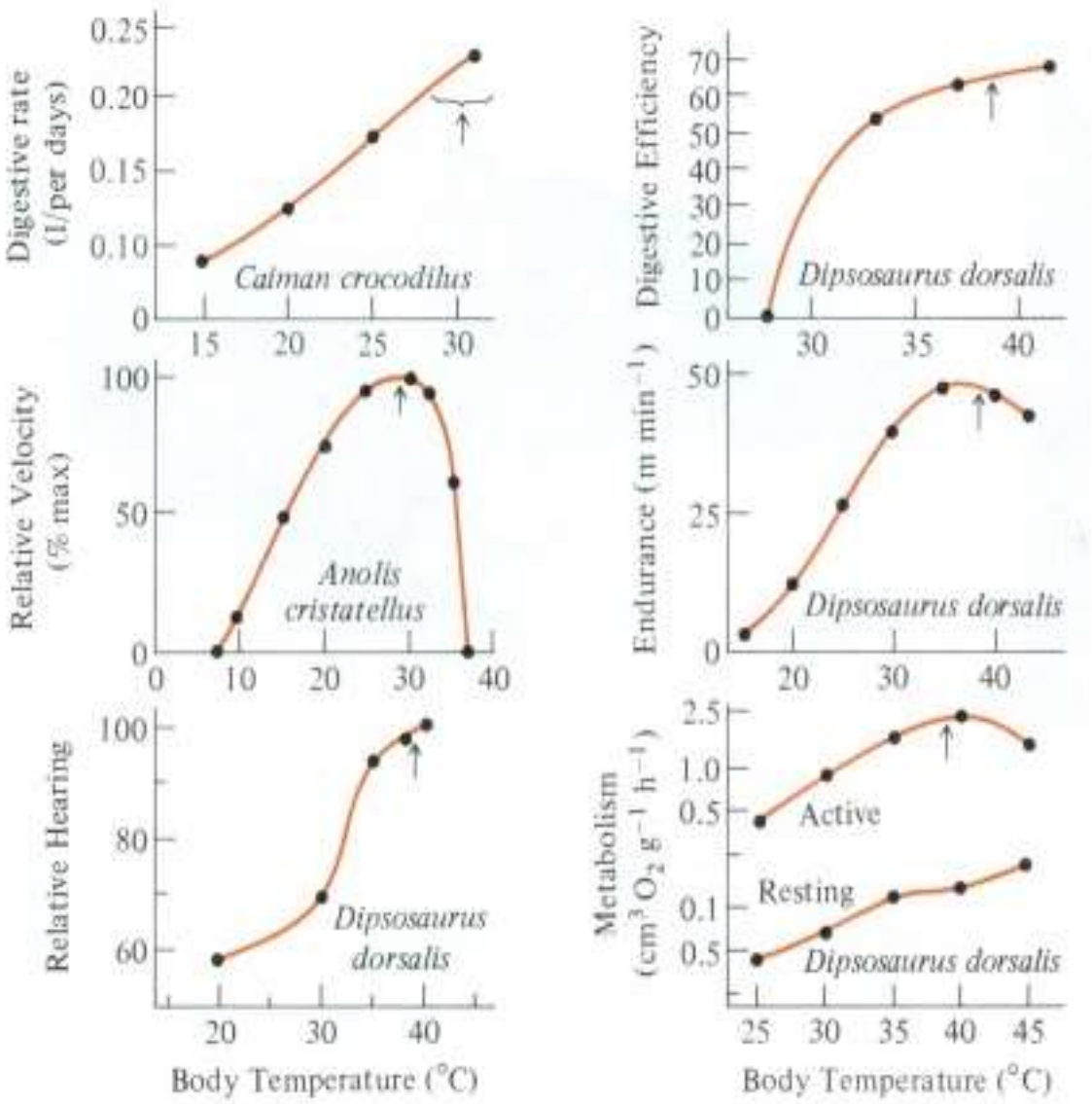
	Source	Route	Influences
Heat gain	The sun	Radiation	Colour, surface properties Size, and exposed surface area Behaviour (posture, orientation, movement)
		Conduction	
		Convection	
	Metabolism		Size and surface area Enzyme concentrations, mitochondrial density Special thermogenic tissues Superficial blood flow, vascular shunts Hormones, nerves Activity
Heat loss		Radiation	Size, surface area, colour, special exposed surfaces Behaviour (posture, orientation, movement) Superficial blood flow, vascular shunts Hormones, nerves Activity
		Conduction	
		Convection	
		Evaporation	Size and surface area Panting, sweating, licking, urinating Superficial blood flow, vascular shunts Hormones, nerves Activity

Terrestrial thermal complexity: microclimates





Many physiological advantages to being hotter

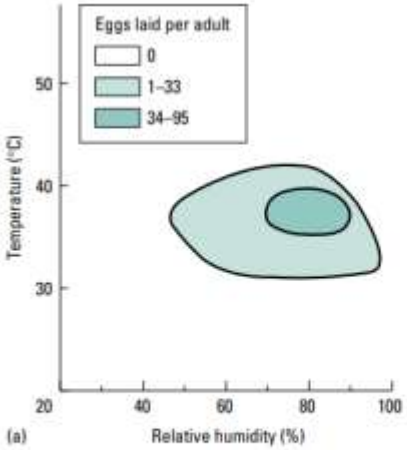


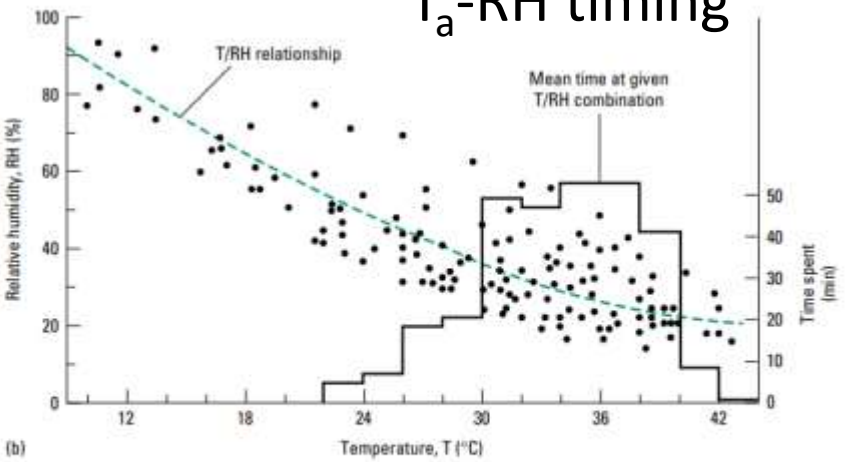
Temperature also affects activities

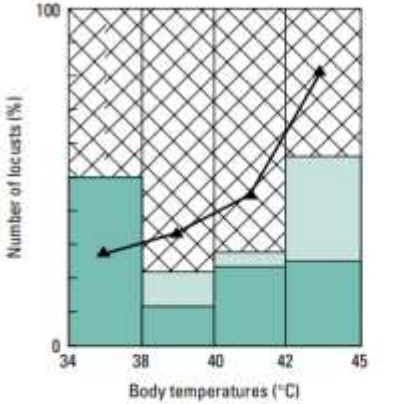
oviposition

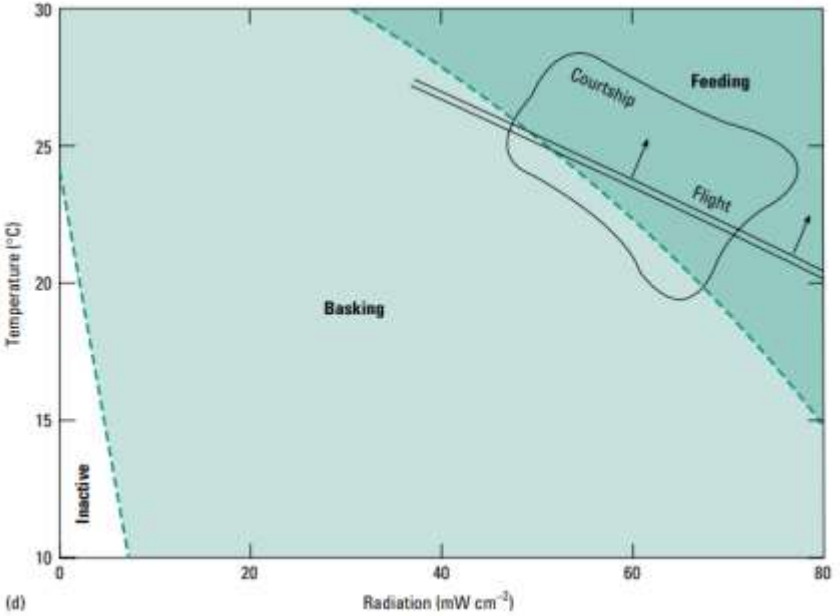
basking

T_a-RH timing



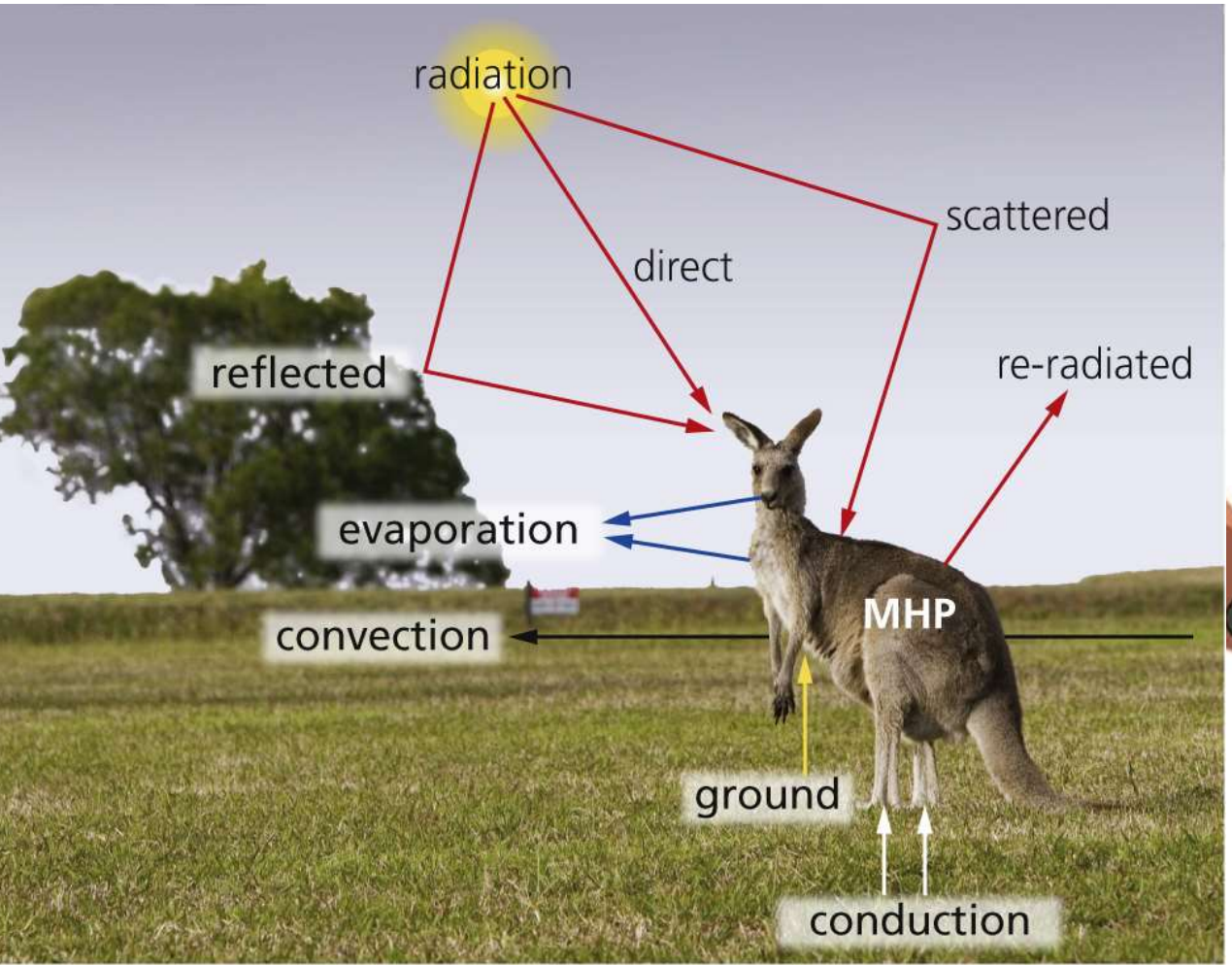


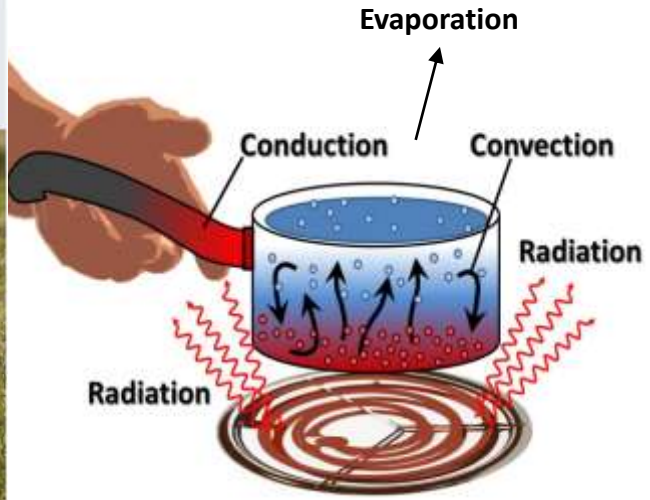




Avenues of heat exchange for an animal

- conduction
- convection
- radiation
- evaporation/condensation



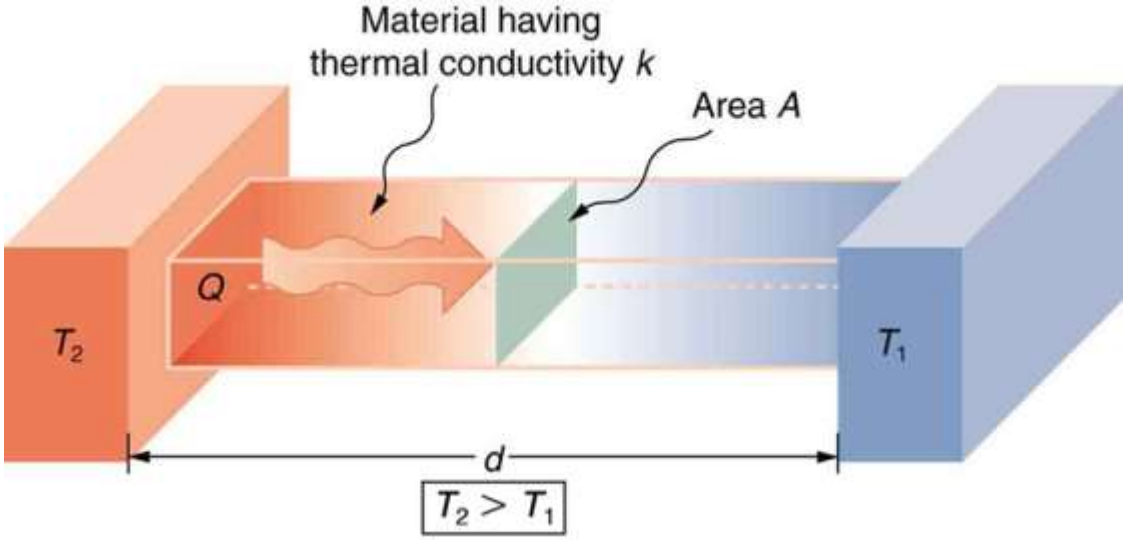


Conduction

Direct contact of two solids (or non-moving fluids).

Heat flux = K A (T_2 - T_1)/L

where K is a physical constant, the thermal conductivity,
A is the area of contact,
(T_2 - T_1) is the thermal differential
L is the distance over which heat has to diffuse.



MATERIAL	K (W/m/°C)
air	0.0025
fat	0.3
water	0.75

Conduction is the reciprocal of insulation

- Still air is the best insulator available!
- fat is a poor insulator and water is even worse

- Conduction is inversely proportional to the thickness of the insulative layer
  (therefore insulation is directly proportional to the thickness)

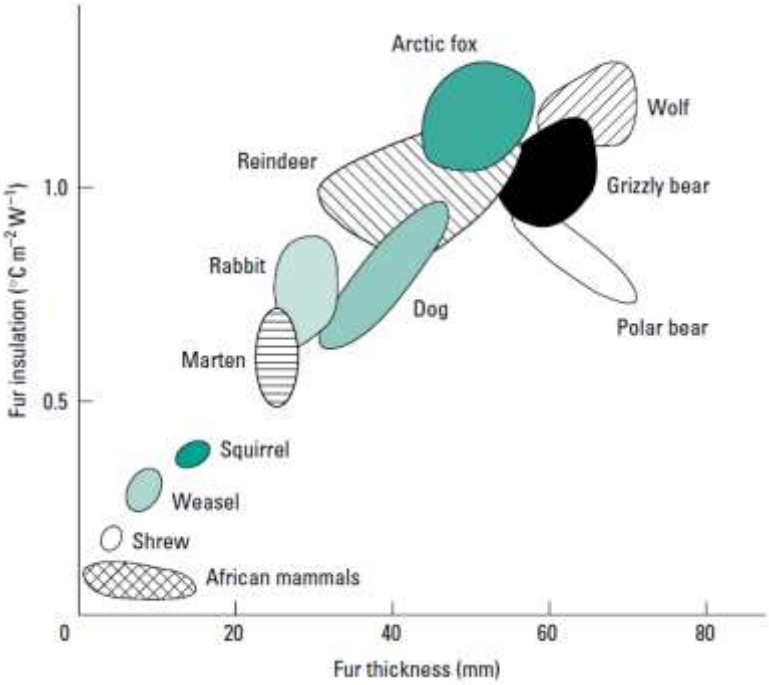


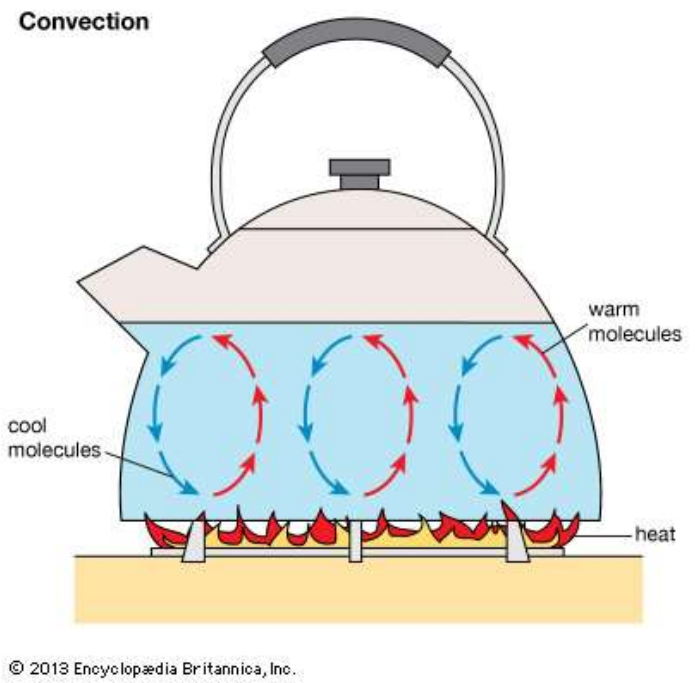
Fig. 8.17 Fur thickness and fur insulation values; small mammals of necessity have short fur, of relatively poor insulation value. Note that these examples are cool temperate and polar species; the fur in African mammals rarely exceeds 15–20 mm in length, and this decreases rather than increases with body size, being only 0.5 mm in the eland (the largest antelope) (see Chapter 16). (Data from Scholander *et al.* 1950; Hofmeyr & Louw 1987.)

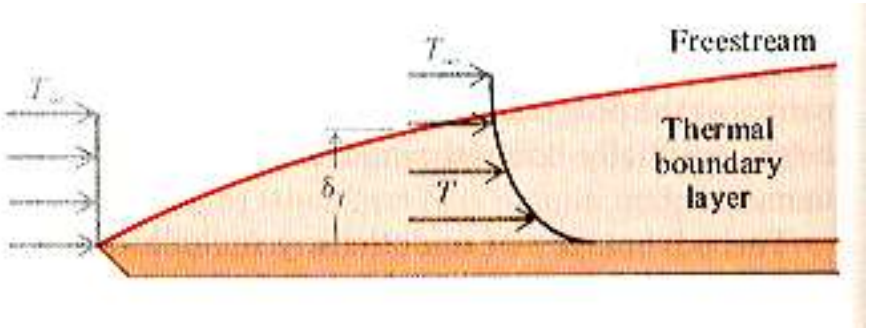
Convection

- the transfer of heat involving a moving fluid (liquid or gas)

- Convection is essentially the transfer of heat by CONDUCTION through the thermal boundary layer around an object

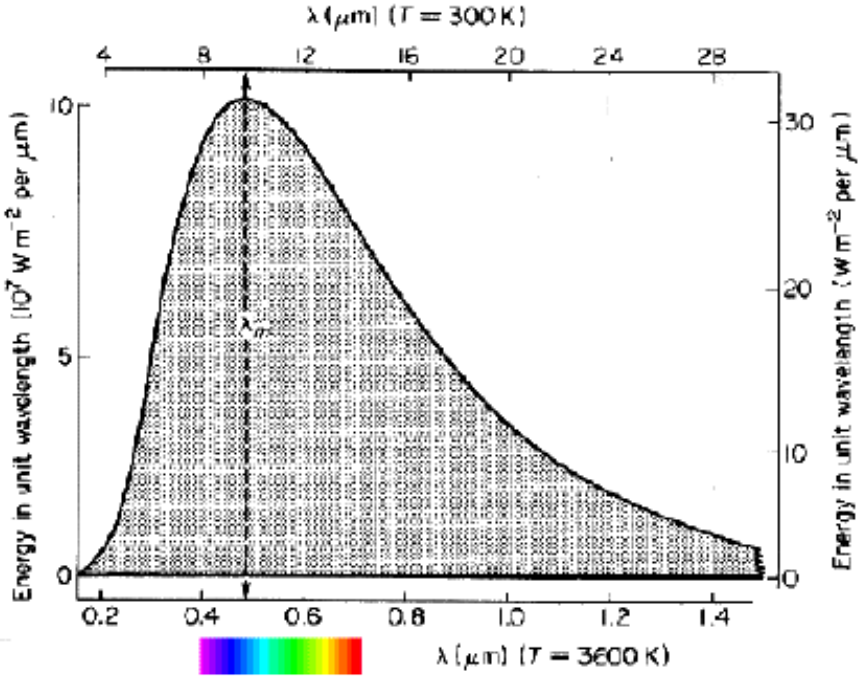
- A thermal boundary layer exists over the surface of an object in a moving fluid (like a the velocity boundary layer)

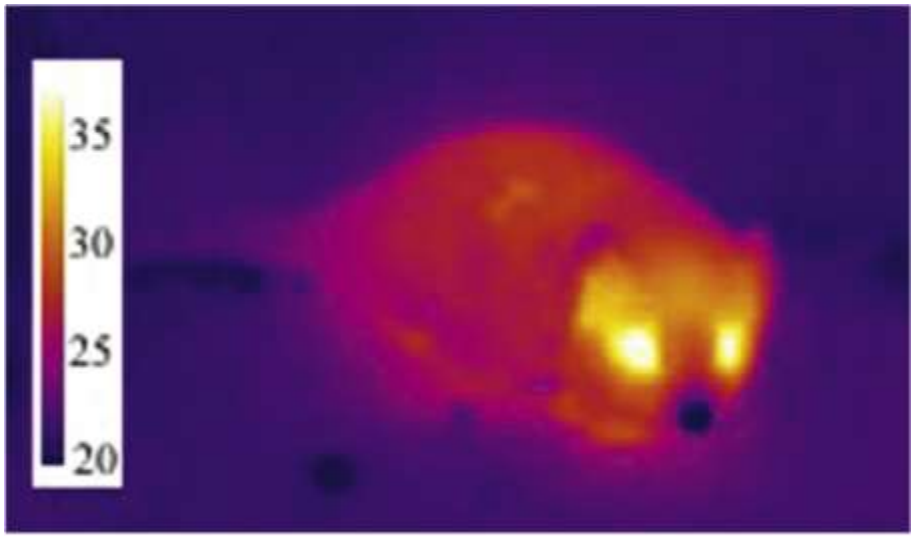




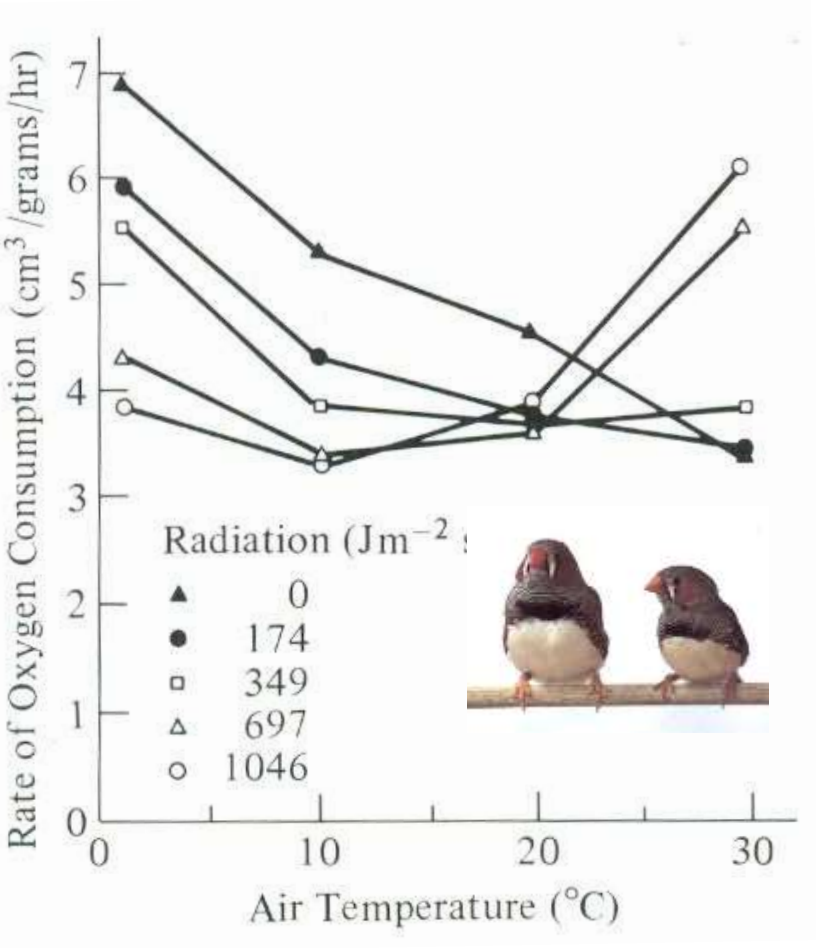
Radiation

- Sun emits light primarily in the "visible" spectrum at high energy since its surface temperature is high (3600 ^{o}K)
- Biological objects emit "light" at much longer wavelengths and lower energy, as their surface temperature is much lower (300 ^{o}K)





With radiative heat load, solar heat is absorbed, which increase body temperature and decreases metabolic rate



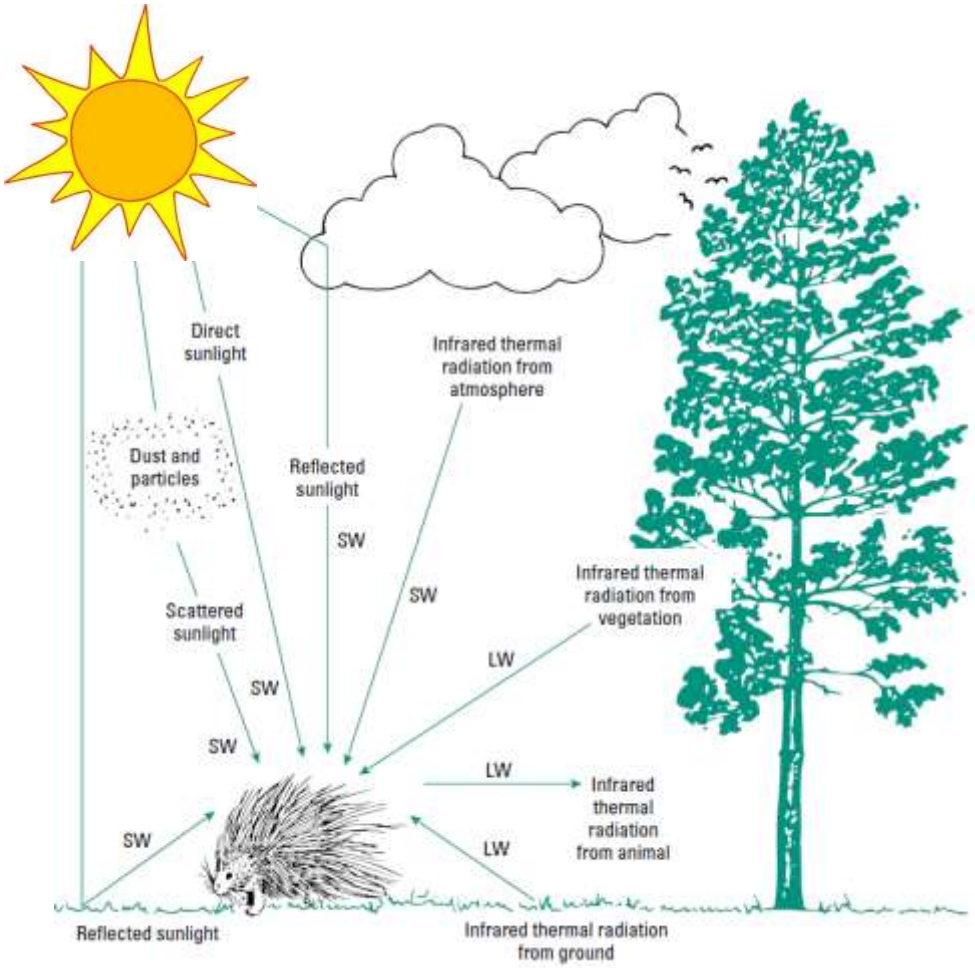


Fig. 8.20 Radiation exchanges for a land animal

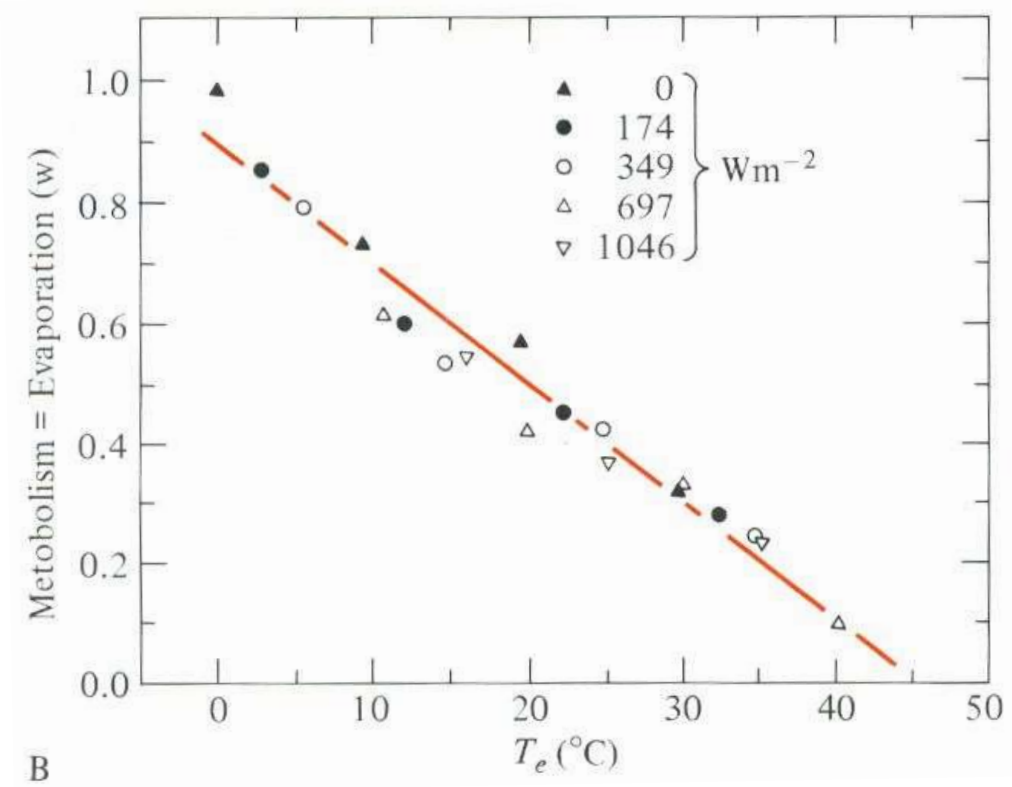
“Air temperature" is not necessarily a useful measure of environmental temperature, especially when there is solar radiation

EQUIVALENT BLACK-BODY TEMPERATURE (T_e)

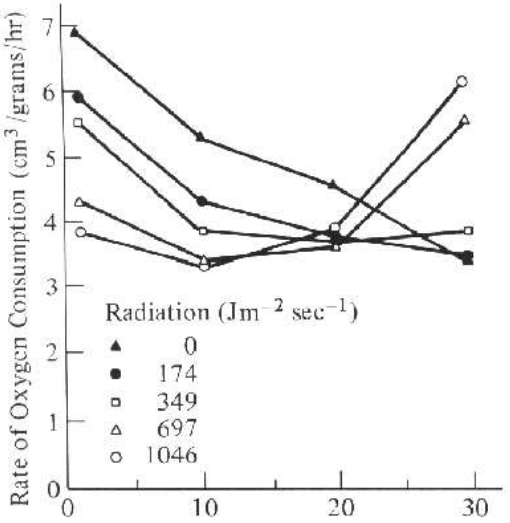
The ambient temperature equivalent to the combined conductive, convective and radiative conditions (ignores metabolic heat production)

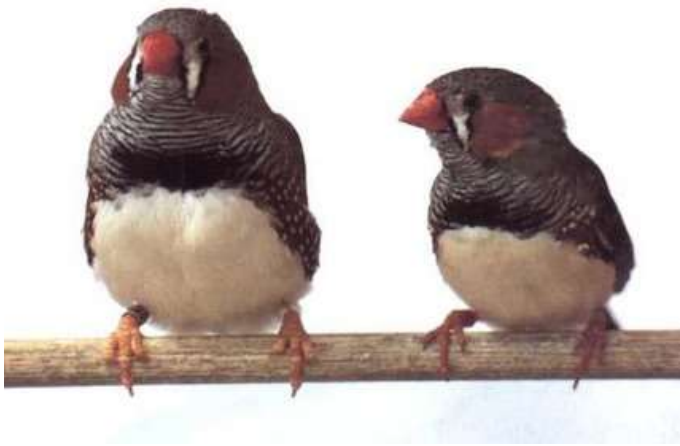
- $T_e = T_{air} + (R_{nir}\, r_e)/(p\, C_p)$
  - R_{nir} is the net isothermal radiation (i.e. radiative heat load)
  - r_e is the environment boundary layer resistance (wind)
  - p is the air density
  - C_p is the air specific heat

- Thus, T_e allows a re-graphing of the metabolic data as

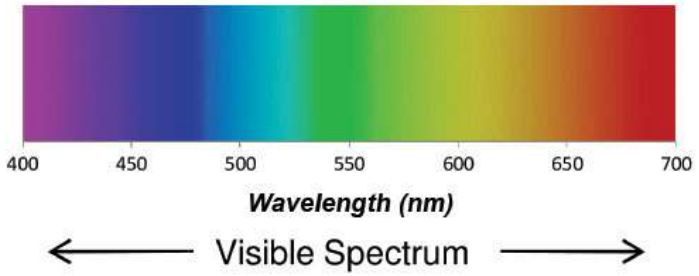


T_e





Colour



Does white reflect heat therefore is cool?

Does black absorb heat therefore is hot?

Other factors that come into account include:

- **surface texture** - fur, feathers, scales, etc
- **reflectance** into the fur/feathers
- advantages of **surface heat trapping**
- effects of **wind speed**

Reflectance of insects using a resource can vary over time of day

(but not much relative to 0-100%!)

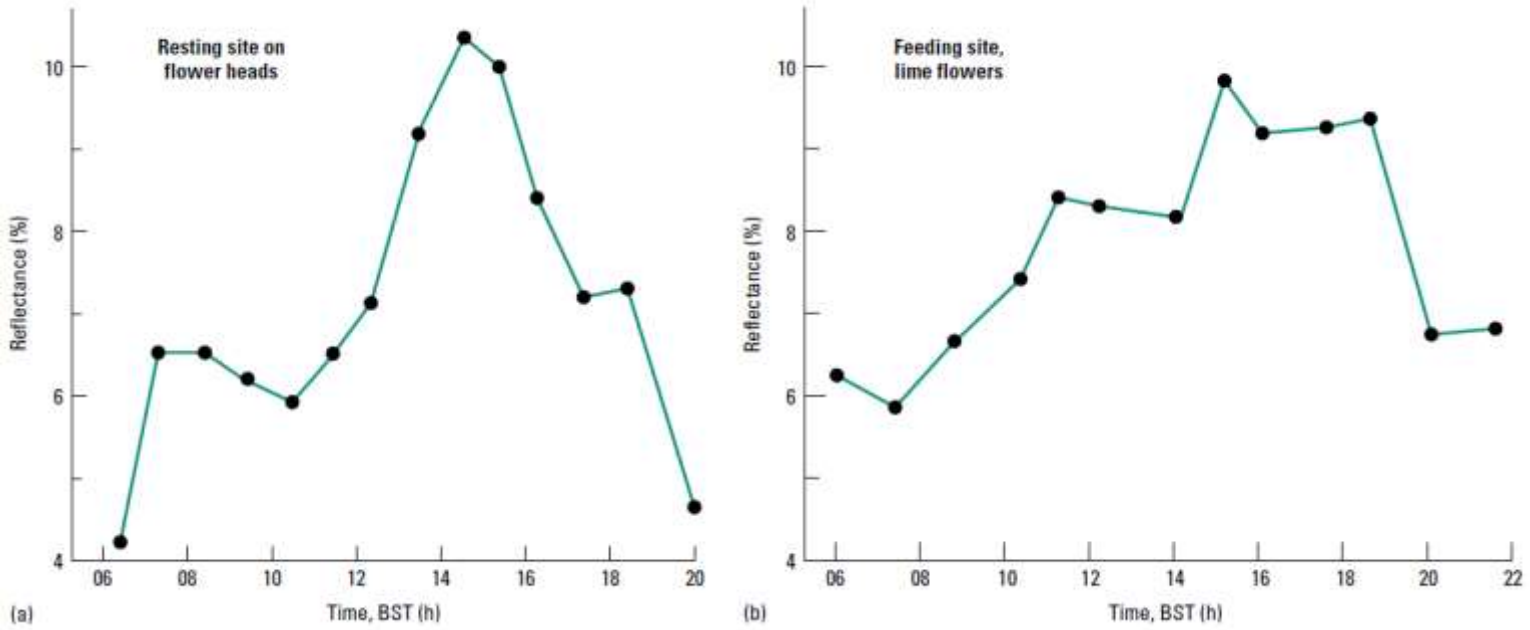


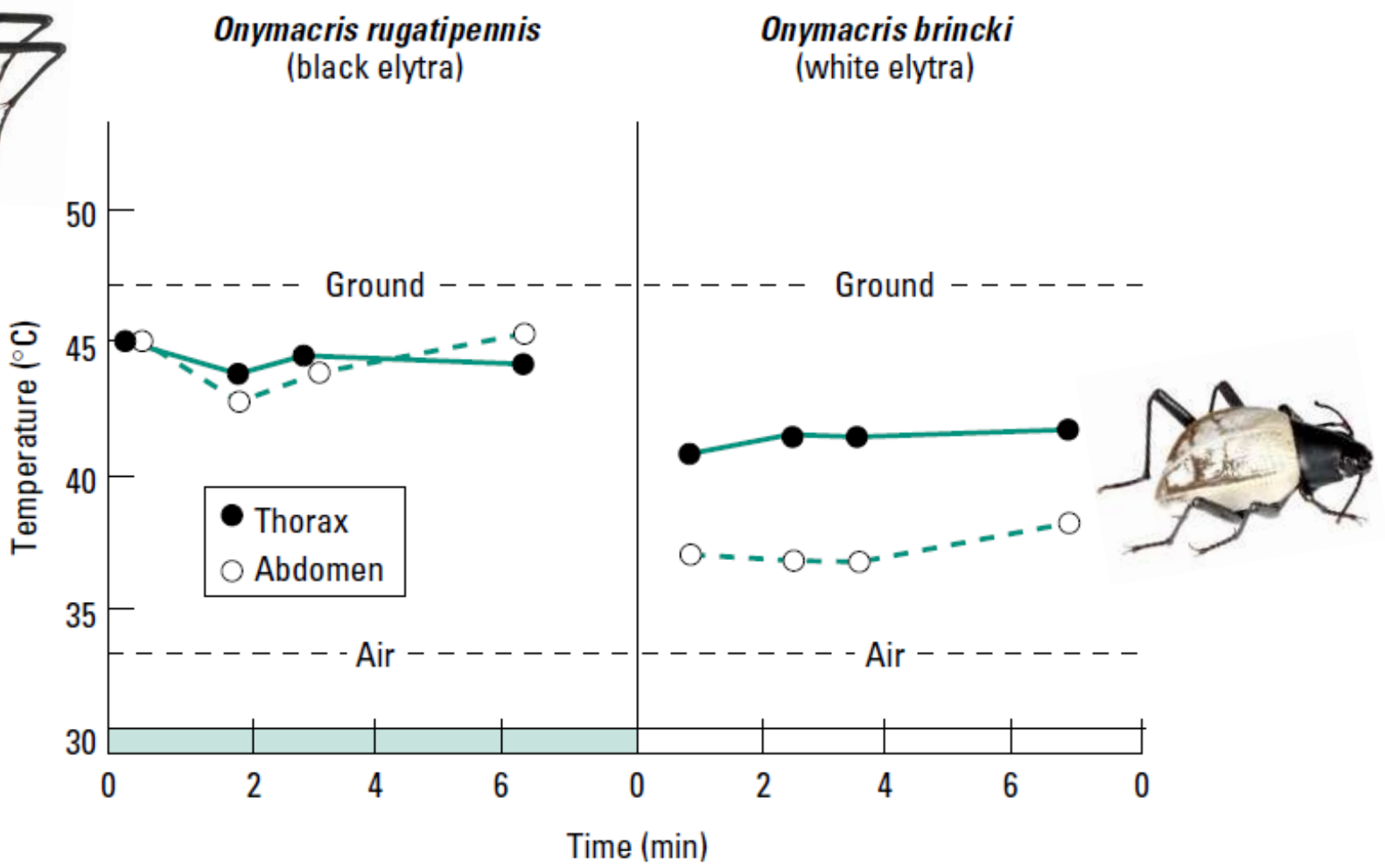
Fig. 15.24 Patterns of insect color (reflectance) through a day at (a) a basking site, and (b) a feeding site on a flower. In both cases dark species are commoner towards dawn and dusk (having higher thermal absorption rates) while only light-colored highly reflective insects are active around midday in full sun. BST, British Summer Time. (From Willmer 1983.)

Is it better to be a black or white beetle?

Why are many desert beetles black?

- to be as hot as possible? MAXITHERMY?
- to absorb then dissipate heat by convection and conduction?
- does melanin in the cuticle offer better resistance to sand abrasion?
- does melanin afford protection against UV radiation (like the black peritoneal pigmentation of some lizards)?

Onymacris beetles



It seems cooler (better) to be white

Evaporation/Condensation

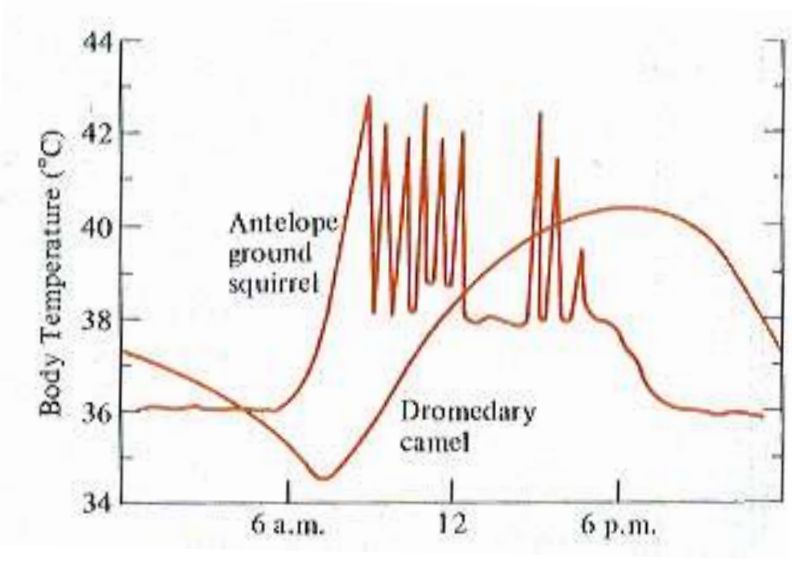
- Latent heat of evaporation is the amount of heat dissipated by the evaporation of water

	Latent Heat Vaporization kJ/kg
Water	2260

- Evaporation can only used to dissipate heat if an animal lives in air
- Good option where water is not in short supply (e.g. intertidal zones, wet tropics)

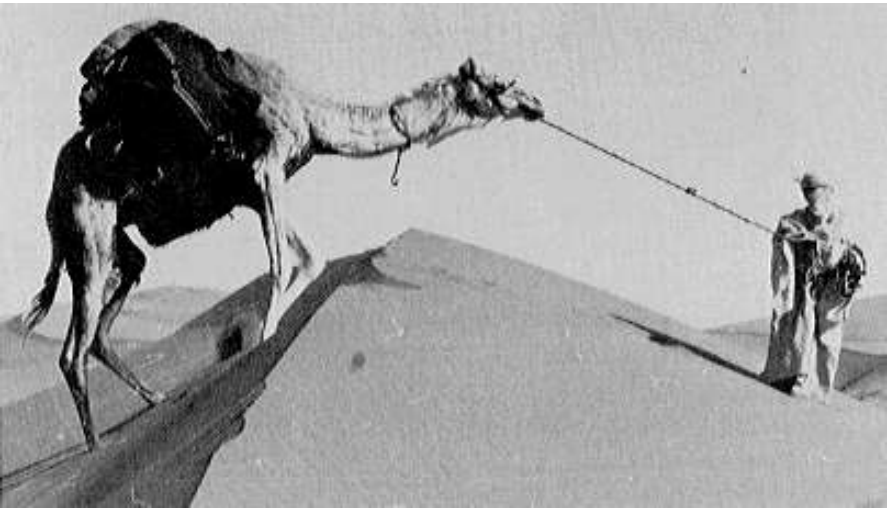
Animal heat storage

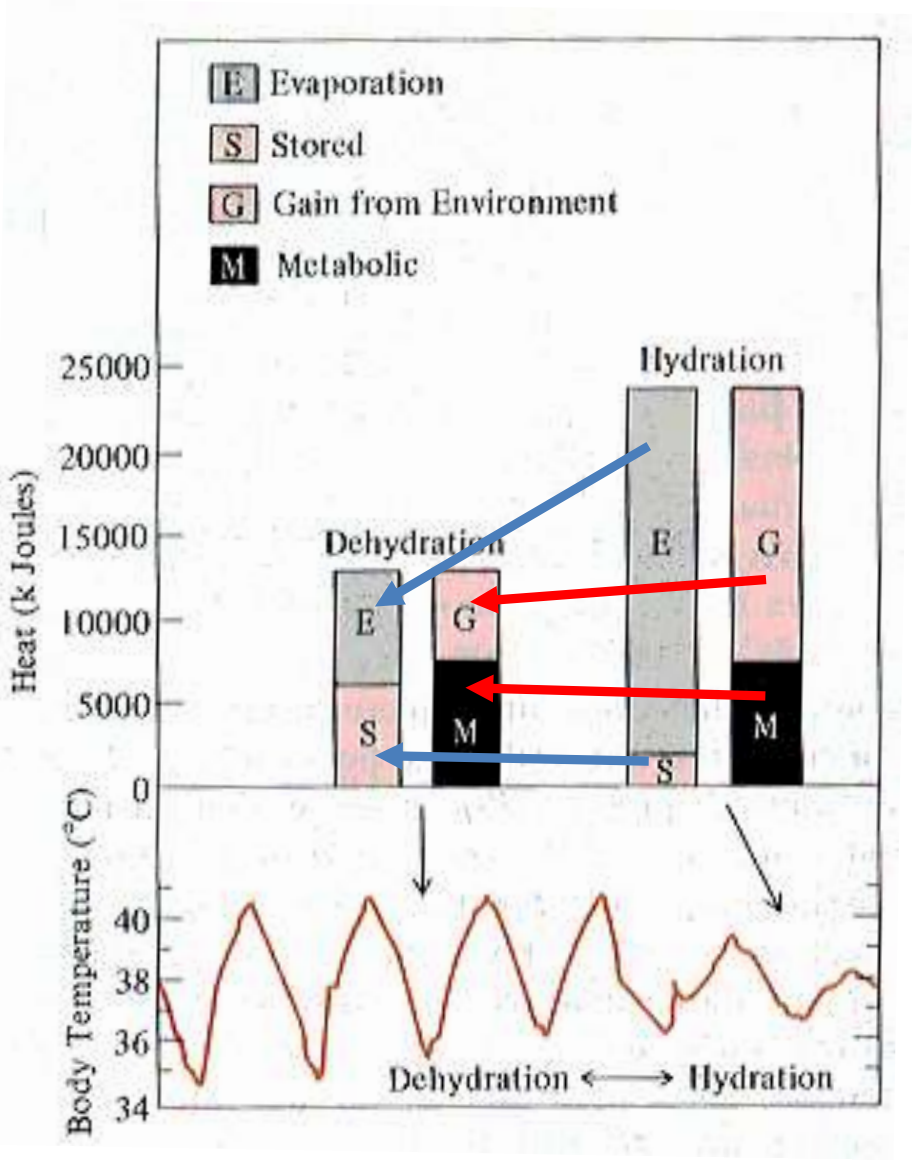
- All tissues have the same capacity to store heat, but an animal's size determines how quickly it heat and cools
- Hyperthermia
  - is important as a **short-term** heat storage mechanism for small animals (e.g. the antelope ground squirrel)
  - is an important **long-term** heat storage mechanism for large animals (e.g. the camel).



Camels have a very large very heat sink

- Big animals that generally cannot escape the desert environment extremes
- Contrast a hydrated and dehydrated camel





Thermal balance equation

For animals, we can sum ALL avenues for heat gain and loss and storage

$$\mathbf{M \pm C_d \pm C_v \pm R \pm E/C = Storage = 0 \text{ in balance}}$$

- **M: Metabolism**. 1 ml O_2 consumed is equivalent to 20.1 joules (but this depends on the RER)
- **C_d: Conduction**
- **C_v: Convection**
- **R: Radiation**
- **E: Evaporation**
- **C: condensation**
- **Storage**

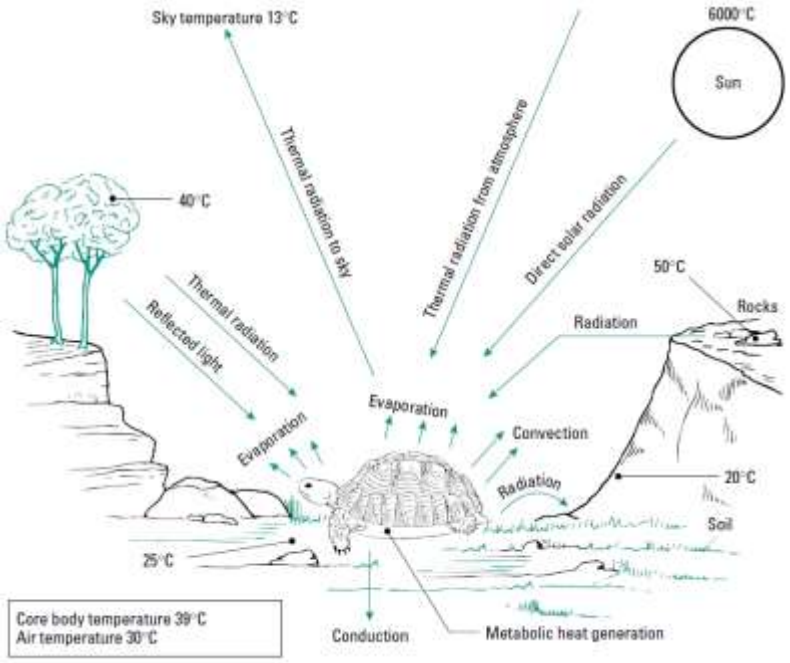


Fig. 8.22 An overview of the thermal exchanges between a terrestrial animal and its environment.